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**AN OPTICAL MAGNIFIER SUITABLE FOR USE WITH A  
MICRODISPLAY DEVICE**

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**AN OPTICAL MAGNIFIER SUITABLE FOR USE WITH A MICRO-  
DISPLAY DEVICE**

This application is a divisional of U.S. Patent application Serial  
No. 10/373,472 filed February 24, 2003, in the name of Cahall, and assigned to the  
5 Eastman Kodak Company.

**FIELD OF THE INVENTION**

This invention relates generally to optical systems and in particular  
to optical magnifiers incorporated into and/or used in conjunction with other  
optical components.

10 **BACKGROUND OF THE INVENTION**

Optical Magnifiers (also referred to as “eyepieces” or “loupes”) are  
known. Typically, these optical devices are used to allow direct viewing of slides  
or other small objects or are used as part of other optical systems such as, for  
example, telescopes and viewfinders.

15 Conventional optical magnifiers utilize magnifier lenses that  
provide an enlarged virtual image of a real object in front of a viewer’s eye. It is  
generally preferable that such lenses, in combination with the object being viewed,  
provide an apparent field of view to the user in excess of +/-10 degrees, in order to  
avoid the sensation of “tunnel vision”. Additionally, these magnifier lenses  
20 preferably provide a relatively long eye relief (that is, the distance at which the  
lens can be held from the eye) in order to allow an object to be comfortably  
viewed.

Optical magnifiers have also been suggested for viewing electronic  
displays incorporated, for example, in portable electronic devices. When used to  
25 view electronic displays, the same criteria, described above, applies, even though  
newer high quality micro-displays are now being manufactured with full diagonals  
of 6 mm or less. In order to obtain a +/-10 degree apparent field of view, such  
small micro-displays require a high magnification lens (on the order of 15x or  
greater), which translates to an effective focal length of approximately 17 mm or  
30 less. As is known, magnification for this type of optical system is calculated using

the standard formula:  $M=254 \text{ mm}/\text{EFL}$ , where EFL is the effective focal length of the lens, measured in mm.

For comfortable viewing by users, including those wearing eyeglasses, it is generally accepted that a reasonable eye relief is approximately 17 mm or greater. As such, in the relative sense, the eye relief should preferably be at least as great as the EFL of the lens (for example, 17 mm in the 15x example described above) for micro-displays of this size. This relationship between eye relief and EFL becomes even more of a concern when shorter focal length (higher magnification) systems are contemplated. This is a new and challenging goal that did not previously exist for larger electronic displays used with correspondingly lower magnification lenses.

In U. S. Pat. No. 4,094,585, E. I. Betensky discloses a three-element all-plastic optical magnifier comprising from the viewing end, a first positive lens group comprising a single element, and a second lens group comprising a bi-convex element and a bi-concave element forming a doublet having the overall shape of a meniscus. This magnifier has a magnification in the range of 13x to 14x. For micro-displays with full diagonals of less than 6 mm, this magnifier does not provide the desired  $\pm 10$  degree field of view. Additionally, this magnifier has the added labor expense of cementing two elements to form a doublet, which may be unacceptable for cost-sensitive applications.

In U. S. Pat. No. 5,835,279, I. Marshall and R. Holmes disclose a three-element all-plastic magnifier lens for viewing an LCD in the binocular vision system of a head-mounded display unit. This design has a large ( $\pm 35.8$  degree) apparent field of view and a long (17 mm) eye relief. However, the LCD is quite large (33.65 mm full diagonal) and the resulting magnification is only about 11x, making it unsuitable for use with micro-displays of the scale contemplated here. Additionally, when this system is scaled to a magnification of 15x, the eye relief drops to about 12.4 mm, quite short for users wearing eyeglasses.

In U. S. Pat. Nos. 5,909,322 and 5,886,825, J. R. Bietry discloses two- and three-element plastic designs for magnifier lenses suitable for use in liquid crystal (LCD) or light emitting diode (LED) micro-display systems.

Although these lenses have a magnification of 16x, high image quality, and long  
5 eye relief, these designs contain at least one diffractive surface, for both the two  
element and three element forms and/or include a rear meniscus lens which is  
concave toward the object and positionable within 5 mm of the object surface. As  
a number of newer "micro-display" devices, for example, LCD devices, depend on  
light being delivered from the front of the display via a polarizing beam splitting  
10 device, a back focal length (BFL) of the lens in excess of 5 mm is often essential  
for the placement of the optical magnifier. For micro-displays which require a  
BFL in excess than 5 mm, these designs will simply not function.

### **SUMMARY OF THE INVENTION**

According to one aspect of the present invention, a magnifier lens  
15 comprises in order from an eye side a first positive power meniscus lens element  
having an eye side surface and an object side surface with at least one of the eye  
side surface and the object side surface is aspheric; and a second positive power  
lens element having an aspheric object side surface convex toward the object side  
and an eye side surface, wherein at least one of the object side surface of the first  
20 positive power meniscus element and the eye side surface of the second positive  
power element is diffractive.

According to another aspect of the invention, an optical system  
comprises in order from an eye side a first positive power meniscus lens element  
having an eye side surface and an object side surface with at least one of the eye  
25 side surface and the object side surface being aspheric; a second positive power  
lens element having an aspheric object side surface convex toward the object side  
and an eye side surface, wherein at least one of the object side surface of the first  
positive power meniscus element and the eye side surface of the second positive  
power element is diffractive; and an object to be viewed.

30 According to another aspect of the invention, a magnifier lens  
comprises in order from an eye side a first positive power lens element having an

aspheric eye side surface; a second negative power meniscus lens element having an aspheric object side surface; and a third positive power bi-convex lens element having at least one aspheric surface.

According to another aspect of the invention, an optical system  
5 comprises in order from an eye side a first positive power lens element having an aspheric eye side surface; a second negative power meniscus lens element having an aspheric object side surface; a third positive power bi-convex lens element having at least one aspheric surface; and an object to be viewed.

According to another aspect of the invention, a magnifier lens  
10 comprises in order from an eye side a first positive power lens element having an aspheric surface; and a second positive power lens element having an aspheric surface, the magnifier lens having a back focal length in air, wherein the back focal length of the magnifier lens in air is greater than 5 mm.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

15 In the detailed description of the preferred embodiments of the invention presented below, reference is made to the accompanying drawings, in which:

FIG.1 shows a sectional view of a first embodiment of the magnifier lens system of the first general form;

20 FIG.2 shows a sectional view of a second embodiment of the magnifier lens system of the first general form;

FIG.3 shows a sectional view of a third embodiment of the magnifier lens system of the first general form;

25 FIG.4 shows a sectional view of a fourth embodiment of the magnifier lens system of the first general form;

FIG.5 shows a sectional view of a first embodiment of the magnifier lens system of the second general form;

FIG.6 shows a sectional view of a second embodiment of the magnifier lens system of the second general form;

30 FIG.7 shows a sectional view of a third embodiment of the magnifier lens system of the second general form;

FIG.8 shows a plot of the through-focus Modulation Transfer Function (MTF) of the magnifier lens illustrated in FIG. 1, the MTF is polychromatic (with equal weights of 510, 560, 610 nm light) at a spatial frequency of 21 line pairs/mm;

5                   FIG.9 shows a plot of the through-focus Modulation Transfer Function (MTF) of the magnifier lens illustrated in FIG. 2, the MTF is polychromatic (with equal weights of 510, 560, 610 nm light) at a spatial frequency of 21 line pairs/mm;

FIG.10 shows a plot of the through-focus Modulation Transfer  
10   Function (MTF) of the magnifier lens illustrated in FIG. 3, the MTF is polychromatic (with equal weights of 510, 560, 610 nm light) at a spatial frequency of 21 line pairs/mm;

FIG.11 shows a plot of the through-focus Modulation Transfer  
Function (MTF) of the magnifier lens illustrated in FIG. 4, the MTF is  
15   polychromatic (with equal weights of 510, 560, 610 nm light) at a spatial frequency of 21 line pairs/mm;

FIG.12 shows a plot of the through-focus Modulation Transfer  
Function (MTF) of the magnifier lens illustrated in FIG. 5, the MTF is  
polychromatic (with equal weights of 510, 560, 610 nm light) at a spatial  
20   frequency of 21 line pairs/mm;

FIG.13 shows a plot of the through-focus Modulation Transfer  
Function (MTF) of the magnifier lens illustrated in FIG. 6, the MTF is  
polychromatic (with equal weights of 510, 560, 610 nm light) at a spatial  
frequency of 21 line pairs/mm; and

25                   FIG.14 shows a plot of the through-focus Modulation Transfer Function (MTF) of the magnifier lens illustrated in FIG. 7, the MTF is polychromatic (with equal weights of 510, 560, 610 nm light) at a spatial frequency of 21 line pairs/mm.

#### **DETAILED DESCRIPTION OF THE INVENTION**

30                   The present description will be directed in particular to elements forming part of, or cooperating more directly with, apparatus in accordance with

the present invention. It is to be understood that elements not specifically shown or described may take various forms well known to those skilled in the art.

In the following descriptions of example embodiments of the invention, the term magnifier lens is used to describe an optical system. However, a person skilled in the art will understand that the magnifier lens(s) described herein can be used as, for example, an eyepiece with other optical components. As such, the term magnifier lens should not be considered limited to any particular application. Note, that since that light can be directed through the magnifier lens in any direction, the eye position can be replaced by a galvanometer or a rotating polygon with some minor distortion adjustments. Thus, a magnifier lens constructed according to the present invention can be used, for example, in scanner applications. The magnifier lens can also be used as part of a viewfinder system in, for example, a digital or hybrid (digital/film) camera to image a scene displayed on an electronic display to a user's eye for preview and/or review.

Referring to FIGS. 1-7, the terms "front" and "rear" refer to the eye side and object side of the magnifier lens, respectively. In the following examples, 10 is the diaphragm of an eye or other instrument, 20 is a polarizing beam splitter (PBS) or other suitable device for dividing light rays, and 30 is a cover plate protecting an object to be viewed (for example, an image display) 40. The PBS 20 is preferably a partially transmissive/partially reflective device used to illuminate the display front-on via a light source located out of the optical path of the magnifier. Typically, in practice, the PBS 20 (or other beam splitting device, or other light dividing device, etc.) is only necessary for objects to be viewed (for example, image displays) 40 that require front-on illumination.

Although the PBS 20 is shown here as perpendicular to the optical axis 60 of the optical system 50, the PBS 20 is typically tilted at some angle or curved along at least one dimension or both. Additionally, the correction of aberrations due to this non-axially symmetric component would require at least one additional non-axially symmetric feature or component. For these reasons, and with simplicity and cost of the optical system 50 in mind, no attempt to

correct aberrations associated with the PBS was made other than inserting the PBS 20 as a thin flat plate oriented perpendicular to the optical axis 60.

The example embodiments of the invention are illustrated in FIGS. 1-7, and Tables 1-7, respectively. In FIGS. 1-7 and Tables 1-7, the surface radii R are numbered beginning at the front side of the magnifier lens 70 ending at the surface of the object to be viewed (for example, an image display surface) 40. In Tables 1-7, the thicknesses of the lens elements and the airspaces between the lens elements are both labeled as "thickness" and are listed on the same line as the surface preceding the thickness. For example, the first thickness in Table 1 corresponds to the distance from the eye diaphragm to the first surface of the first element  $E_1$ . Similarly, the second thickness in Table 1 corresponds to the thickness of the first element  $E_1$  in the system. All thicknesses provided in Tables 1-7 are in millimeters. All indices and V-numbers (also known as Abbe numbers) are for the helium d line of the spectrum at a wavelength of 587.6 nm. Additionally, the example embodiments are color-corrected for the visible spectrum by modeling the photopic response of the human eye using equal weights of 510, 560, and 610 nm light.

A magnifier lens 70 of a first example embodiment is depicted in FIG. 1. This magnifier lens 70 includes two lens elements  $E_1$  and  $E_2$ . The first lens element  $E_1$  is a positive power meniscus element concave toward the rear, object side. The front, eye side surface of element  $E_1$  is aspheric and the rear, object side surface of element  $E_1$  is spherical. The second lens element  $E_2$  is a positive power meniscus lens element as well. The front, eye side surface of element  $E_2$  is a diffractive and the rear, object side surface of element  $E_2$  is aspheric. Elements  $E_1$  and  $E_2$  are made of plastic and can be molded. The total thickness of the magnifier lens 70, including elements  $E_1$  and  $E_2$  and the airspace between them, is about 8.6 mm. The total thickness from the front, eye side surface of  $E_1$  to the surface of the object to be viewed (for example, an image display surface) 40 is about 16.7 mm.

A magnifier lens 70 of a second example embodiment is depicted in FIG. 2. This magnifier lens 70 includes two lens elements  $E_1$  and  $E_2$ . The first



lens element  $E_1$  is a positive power meniscus element concave toward the rear, object side. The front, eye side surface of element  $E_1$  is spherical and the rear, object side surface of element  $E_1$  is aspheric. The second lens element  $E_2$  is a positive power meniscus lens element as well. The front, eye side surface of  
5 element  $E_2$  is a diffractive and the rear, object side surface of element  $E_2$  is aspheric. Elements  $E_1$  and  $E_2$  are made of plastic and can be molded. The total thickness of the magnifier lens 70, including elements  $E_1$  and  $E_2$  and the airspace between them, is about 8.6 mm. The total thickness from the front, eye side surface of  $E_1$  to the surface of the object to be viewed (for example, an image  
10 display surface) 40 is about 16.9 mm.

A magnifier lens 70 of a third example embodiment is depicted in FIG. 3. This magnifier lens 70 includes two lens elements  $E_1$  and  $E_2$ . The first lens element  $E_1$  is a positive power meniscus element concave toward the rear, object side. The front, eye side surface of element  $E_1$  is aspheric and the rear,  
15 object side surface of element  $E_1$  is diffractive. The second lens element  $E_2$  is a positive power meniscus lens element as well. The front, eye side surface of element  $E_2$  is spherical and the rear, object side surface of element  $E_2$  is aspheric. Elements  $E_1$  and  $E_2$  are made of plastic and can be molded. The total thickness of the magnifier lens 70, including these two elements and the airspace between  
20 them, is about 8.1 mm. The total thickness from the front, eye side surface of  $E_1$  to the surface of the object to be viewed (for example, an image display surface) 40 is about 16.2 mm.

A magnifier lens 70 of a fourth example embodiment is depicted in FIG. 4. This magnifier lens 70 includes two lens elements  $E_1$  and  $E_2$ . The first  
25 lens element  $E_1$  is a positive power meniscus element concave toward the rear, object side. The front, eye side surface of element  $E_1$  is aspheric and the rear, object side surface of element  $E_1$  is diffractive. The second lens element  $E_2$  is a positive power bi-convex lens element. The front, eye side surface of element  $E_2$  is spherical and the rear, object side surface of element  $E_2$  is aspheric. Elements  
30  $E_1$  and  $E_2$  are made of plastic and can be molded. The total thickness of the magnifier lens 70, including these two elements and the airspace between them, is

about 8.4 mm. The total thickness from the front, eye side surface of  $E_1$  to the surface of the object to be viewed (for example, an image display surface) 40 is about 16.5 mm.

A magnifier lens 70 of a fifth example embodiment is depicted in FIG. 5. This magnifier lens 70 includes three lens elements  $E_1$ ,  $E_2$ , and  $E_3$ . The first lens element  $E_1$  is a positive power bi-convex element. The front, eye side surface of element  $E_1$  is aspheric (simple conic) and the rear, object side surface of element  $E_1$  is spherical. The second lens element  $E_2$  is a negative power meniscus lens element convex toward the eye side. The front, eye side surface of element  $E_2$  is spherical and the rear, object side surface of element  $E_2$  is aspheric (simple conic). The third lens element  $E_3$  is a positive power bi-convex element. The front, eye side surface of element  $E_3$  is spherical and the rear, object side surface of element  $E_3$  is aspheric. Elements  $E_1$ ,  $E_2$ , and  $E_3$  are made of plastic and can be molded. The total thickness of the magnifier lens 70, including these three elements and the airspaces between them, is about 9.8 mm. The total thickness from the front, eye side surface of  $E_1$  to the surface of the object to be viewed (for example, an image display surface) 40 is about 17.9 mm.

A magnifier lens 70 of a sixth example embodiment is depicted in FIG. 6. This magnifier lens 70 includes three lens elements  $E_1$ ,  $E_2$ , and  $E_3$ . The first lens element  $E_1$  is a positive power meniscus element, convex toward the eye side. The front, eye side surface of element  $E_1$  is aspheric and the rear, object side surface of element  $E_1$  is spherical. The second lens element  $E_2$  is a negative power meniscus lens element convex toward the eye side. The front, eye side surface of element  $E_2$  is spherical and the rear, object side surface of element  $E_2$  is aspheric (simple conic). The third lens element  $E_3$  is a positive power bi-convex element. The front, eye side surface of element  $E_3$  is spherical and its rear, object side surface is aspheric. Elements  $E_1$ ,  $E_2$ , and  $E_3$  are made of plastic and can be molded. The total thickness of the magnifier lens 70, including these three elements and the airspaces between them, is about 9.5 mm. The total thickness from the front, eye side surface of  $E_1$  to the surface of the object to be viewed (for example, an image display surface) 40 is about 17.2 mm.

A magnifier lens 70 of a seventh example embodiment is depicted in FIG. 7. This magnifier lens 70 includes three lens elements  $E_1$ ,  $E_2$ , and  $E_3$ . The first lens element  $E_1$  is a positive power bi-convex element. The front, eye side surface of element  $E_1$  is aspheric (simple conic) and the rear, object side surface of element  $E_1$ , is spherical. The second lens element  $E_2$  is a negative power meniscus lens element convex toward the eye side. The front, eye side surface of element  $E_2$  is spherical and the rear, object side surface of element  $E_2$  is aspheric (simple conic). The third lens element  $E_3$  is a positive power bi-convex element. The front, eye side surface of element  $E_3$  is aspheric and the rear, object side surface of element  $E_3$  is spherical. Elements  $E_1$ ,  $E_2$ , and  $E_3$  are made of plastic and can be molded. The total thickness of the magnifier lens 70, including these three elements and the airspaces between them, is about 9.3 mm. The total thickness from the front, eye side surface of  $E_1$  to the surface of the object to be viewed (for example, an image display surface) 40 is about 17.6 mm.

The seven example embodiments described above are designed for an object semi-diagonal of 2.4 mm. These embodiments have effective focal lengths between 12.87 mm and 13.05 mm and corresponding magnifications between 19.7x and 19.5x, respectively. Embodiments 1-7 have an apparent field of view of  $\pm 10.5$  degrees, an eye relief of 17 mm, and assume a pupil diameter of 6 mm. The resulting relative aperture of embodiments 1-7 is about  $f/2.2$ . The seven example embodiments have a maximum distortion (absolute value)  $< 1\%$  and a primary lateral chromatic aberration (absolute value)  $< 3$  microns. Additionally, any one or all of the individual lens elements described above can be made using glass in conjunction with a grinding and polishing or molding manufacturing process.

The embodiments described above are suitable for use with LCD-type micro-displays. This is made possible by designing the magnifier lenses 70 to be approximately telecentric on the display side (i.e., chief rays nearly parallel to the optical axis of the system, which is itself parallel to the display surface normal). It is known that doing so reduces perceived brightness falloff toward the corners of the display (which can be substantial with non-telecentric lenses). In

embodiments 1-7, the maximum chief ray angle (absolute value) on the display side for all of these embodiments is  $< 3$  degrees. Additionally, the embodiments described above are suitable for use with other types of electronic displays and micro-displays, for example, light emitting diode displays such as organic light emitting diode displays, polymeric light emitting diode displays, etc.

Additionally, embodiments 1-7 employ vignetting at the front, eye side surface of the first element  $E_1$ . Vignetting stops some aberrated rays near the edge of the pupil from reaching off-axis points in the image plane. This increases off-axis image quality at the expense of reduced illumination in the corners of the image relative to that at the center of the image (i.e., relative illumination). Vignetting in the corner of the image is between 25% and 35% for the embodiments described above. This is well within the (generally accepted) 30-40% vignetting that the human eye can tolerate before it becomes noticeable.

It is well known by those skilled in the art of magnifier design that the human eye can accommodate some degree of field curvature by effectively refocusing (the eye) for different parts of the field. The eye can also tolerate some (typically, lesser) degree of astigmatism. Traditionally, when the tangential and sagittal field curves all lie within 1 diopter of the central focus, the image is reasonably well defined over the field. Also, in the absence of astigmatism, a young observer can focus on the field edge and accommodate about 3 diopters for the center. In embodiments 1-7, the image is permitted to curve somewhat, thereby facilitating the reduction of astigmatism in the magnifier lenses. The result is essentially just some degree of field curvature (from the lenses) and the astigmatism associated with the PBS. For the embodiments described above, the curvature of the field corresponds to an accommodation of  $< 0.6$  diopters between the center and the edge of the field.

The through-focus MTF plots shown in FIGS. 8-14 are polychromatic (equal weights of 510 nm, 560 nm, and 610 nm light) for the embodiments depicted in FIGS. 1-7, and Tables 1-7, respectively. The MTF plots are shown for 21 line pairs/mm, half the nyquist frequency for a display with

0.012 mm square pixels. Each MTF plot assumes a curved image surface with radius as given in the prescriptions of Tables 1-7.

It should be noted that for the embodiments in FIGS. 5-7 and Tables 5-7, respectively, the polychromatic MTF performance is substantially the same for equal weights of 450 nm, 550 nm, and 650 nm. For the embodiments in FIGS. 1-4 and Tables 1-4, respectively, the polychromatic MTF performance drops somewhat for equal weights of 450 nm, 550 nm, and 650 nm, but may be recovered quite well with a quick re-optimization.

**TABLE 1**

SURF.	CLEAR APER.	RADIUS	THICKNESS	INDEX	V-NUMBER
	6.00	DIAPHRAGM	17.000		
1	10.20*	ASPHERE(1)	3.710	1.492	57.8
2	9.14	16.4892	1.900		
3	8.62	-22.2252(2)	2.972	1.590	30.8
4	7.90	ASPHERE(1)	2.443		
5	6.79	PLANO	0.330	1.550	55.0
6	6.71	PLANO	4.635		
7	4.93	PLANO	0.725	1.570	55.0
8	4.82	-30.5417			

\*DO NOT EXCEED LENS LENGTH 8.582

NOTES:

1) ASPHERIC SURFACE DESCRIBED BY SAG EQUATION:

$$X(Y) = \frac{CY^2}{1 + \sqrt{1 - (k+1)C^2Y^2}} + DY^4 + EY^6 + FY^8 + GY^{10} + HY^{12}$$

SURF. 1 C= 0.1666667 D= -0.28952730E-03 F= -0.93959591E-06  
k= 0.0000000 E= 0.90649168E-05 G= 0.35556391E-07  
VERTEX RADIUS (1/C) = 6.0000 H= -0.57183989E-09

SURF. 4 C= -0.0897376 D= 0.79693786E-03 F= 0.24127936E-05  
k= 0.0000000 E= 0.16847998E-05 G= -0.17226572E-06  
VERTEX RADIUS (1/C) = -11.1436 H= 0.65623726E-08

2) DIFFRACTIVE SURFACE DESCRIBED BY PHASE EQUATION:

$$\Phi(Y) = \frac{2\pi}{\lambda_0} (C_1Y^2 + C_2Y^4 + C_3Y^6 + C_4Y^8)$$

SURF. 3  $\lambda_0 = 560$  NM  $C_1 = -4.12013E-03$   $C_3 = -3.46267E-06$   
 $C_2 = 7.96815E-05$   $C_4 = 1.07025E-07$

**TABLE 2**

SURF.	CLEAR APER.	RADIUS	THICKNESS	INDEX	V-NUMBER
	6.00	DIAPHRAGM	17.000		
1	10.20*	6.229	3.851	1.492	57.8
2	9.11	ASPHERE(1)	1.807		
3	8.69	-13.0221(2)	2.946	1.590	30.8

4	8.14	ASPHERE(1)	2.594		
5	6.82	PLANO	0.330	1.550	55.0
6	6.74	PLANO	4.635		
7	4.93	PLANO	0.725	1.570	55.0
8	4.82	-30.5417			

\*DO NOT EXCEED LENS LENGTH 8.604

NOTES:

3) ASPHERIC SURFACE DESCRIBED BY SAG EQUATION:

$$X(Y) = \frac{CY^2}{1 + \sqrt{1 - (k+1)C^2Y^2}} + DY^4 + EY^6 + FY^8 + GY^{10} + HY^{12}$$

SURF. 2	C=	0.4044146	D=	0.52788255E-03	F=	0.48822016E-06
	k=	0.0000000	E=	-0.51777047E-05	G=	-0.48083647E-07
	VERTEX RADIUS (1/C)	=	24.7271		H=	0.36767183E-09

SURF. 4	C=	-0.1093386	D=	0.64198372E-03	F=	0.35968081E-05
	k=	0.0000000	E=	-0.11253640E-04	G=	-0.21871596E-06
	VERTEX RADIUS (1/C)	=	-9.1459		H=	0.74093706E-08

4) DIFFRACTIVE SURFACE DESCRIBED BY PHASE EQUATION:

$$\Phi(Y) = \frac{2\pi}{\lambda_0} (C_1Y^2 + C_2Y^4 + C_3Y^6 + C_4Y^8)$$

SURF. 3	$\lambda_0$	=	560 NM	$C_1$	=	-4.06429E-03	$C_3$	=	-3.73155E-06
				$C_2$	=	7.15512E-05	$C_4$	=	1.62241E-07

TABLE 3

SURF.	CLEAR APER.	RADIUS	THICKNESS	INDEX	V-NUMBER
	6.00	DIAPHRAGM	17.000		
1	10.20*	ASPHERE(1)	4.091	1.492	57.8
2	8.95	19.2401(2)	1.264		
3	8.57	-39.0234	2.750	1.590	30.8
4	7.56	ASPHERE(1)	2.441		
5	6.63	PLANO	0.330	1.550	55.0
6	6.56	PLANO	4.635		
7	4.92	PLANO	0.725	1.570	55.0
8	4.83	-30.5417			

\*DO NOT EXCEED LENS LENGTH 8.105

NOTES:

5) ASPHERIC SURFACE DESCRIBED BY SAG EQUATION:

$$X(Y) = \frac{CY^2}{1 + \sqrt{1 - (k+1)C^2Y^2}} + DY^4 + EY^6 + FY^8 + GY^{10} + HY^{12}$$

SURF. 1	C=	0.1646063	D=	-0.20370475E-03	F=	-0.70916812E-06
	k=	0.0000000	E=	0.86070374E-05	G=	0.24289232E-07
	VERTEX RADIUS (1/C)	=	6.0751		H=	-0.31512663E-09

SURF. 4	C=	-0.0603912	D=	0.95297402E-03	F=	0.62224391E-05
	k=	0.0000000	E=	-0.15864043E-04	G=	-0.47132486E-06
	VERTEX RADIUS (1/C)	=	-16.5587		H=	0.17717982E-07

6) DIFFRACTIVE SURFACE DESCRIBED BY PHASE EQUATION:

$$\Phi(Y) = \frac{2\pi}{\lambda_0} (C_1Y^2 + C_2Y^4 + C_3Y^6 + C_4Y^8)$$

SURF. 2     $\lambda_0 = 560 \text{ NM}$

$C_1 = -3.32269\text{E-}03$	$C_3 = -1.71275\text{E-}06$
$C_2 = 4.52118\text{E-}05$	$C_4 = 5.78513\text{E-}08$

TABLE 4

SURF.	CLEAR APER.	RADIUS	THICKNESS	INDEX	V-NUMBER
	6.00	DIAPHRAGM	17.000		
1	10.20*	ASPHERE(1)	4.294	1.492	57.8
2	8.55	8.1991(2)	1.349		
3	8.38	21.6332	2.750	1.590	30.8
4	7.62	ASPHERE(1)	2.441		
5	6.67	PLANO	0.330	1.550	55.0
6	6.59	PLANO	4.635		
7	4.93	PLANO	0.725	1.570	55.0
8	4.81	-30.5417			

\*DO NOT EXCEED LENS LENGTH 8.393

NOTES:

7) ASPHERIC SURFACE DESCRIBED BY SAG EQUATION:

$$X(Y) = \frac{CY^2}{1 + \sqrt{1 - (k+1)C^2Y^2}} + DY^4 + EY^6 + FY^8 + GY^{10} + HY^{12}$$

SURF. 1    C=    0.1682086    D= -0.36386441E-03    F= -0.13188881E-05  
           k=    0.0000000    E= 0.12936727E-04    G= 0.50574451E-07  
           VERTEX RADIUS (1/C) =    5.945    H= -0.93964616E-09

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SURF. 4  C=   -0.0426814    D=  0.71989155E-03    F=  0.27592984E-05
          k=    0.0000000    E= -0.41520397E-05    G= -0.20084234E-06
          VERTEX RADIUS (1/C) = -23.4294          H=  0.85266176E-08

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8) DIFFRACTIVE SURFACE DESCRIBED BY PHASE EQUATION:

$$\Phi(Y) = \frac{2\pi}{\lambda_0} (C_1 Y^2 + C_2 Y^4 + C_3 Y^6 + C_4 Y^8)$$

SURF. 2     $\lambda_0 = 560 \text{ NM}$      $C_1 = -3.74332\text{E-}03$      $C_3 = 4.01070\text{E-}06$   
     $C_2 = -5.34761\text{E-}05$      $C_4 = -4.14056\text{E-}08$

TABLE 5

CLEAR					
SURF.	APER.	RADIUS	THICKNESS	INDEX	V-NUMBER
	6.00	DIAPHRAGM	17.000		
1	9.10*	ASPHERE(1)	3.380	1.492	57.8
2	8.73	-104.3823	0.181		
3	8.52	32.1466	1.449	1.583	30.1
4	7.57	ASPHERE(1)	1.053		
5	7.99	6.9618	3.698	1.492	57.8
6	7.85	ASPHERE(1)	2.444		
7	6.73	PLANO	0.330	1.550	55.0
8	6.66	PLANO	4.635		
9	4.95	PLANO	0.725	1.570	55.0
10	4.82	-28.7621			

\*DO NOT EXCEED LENS LENGTH 9.761

NOTES:

1) ASPHERIC SURFACE DESCRIBED BY SAG EQUATION:

$$X(Y) = \frac{CY^2}{1 + \sqrt{1 - (k+1)C^2Y^2}} + DY^4 + EY^6 + FY^8 + GY^{10} + HY^{12}$$

SURF. 1 C= 0.1582487 D= 0.0000000E+00 F= 0.0000000E+00  
k= -1.2126760 E= 0.0000000E+00 G= 0.0000000E+00  
VERTEX RADIUS (1/C) = 6.3194 H= 0.0000000E+00

SURF. 4 C= 0.2284044 D= 0.0000000E+00 F= 0.0000000E+00  
k= -0.7743398 E= 0.0000000E+00 G= 0.0000000E+00  
VERTEX RADIUS (1/C) = 4.3782 H= 0.0000000E+00

SURF. 6 C= -0.0868644 D= 0.4399801E-03 F= -0.3529413E-06  
k= 0.0000000 E= 0.4799854E-05 G= 0.8495183E-08  
VERTEX RADIUS (1/C) = -11.5122 H= 0.0000000E+00

TABLE 6

SURF.	CLEAR APER.	RADIUS	THICKNESS	INDEX	V-NUMBER
	6.00	DIAPHRAGM	17.000		
1	9.10*	ASPHERE(1)	3.188	1.492	57.8
2	8.69	95.4845	0.335		
3	8.50	26.9536	1.280	1.583	30.1
4	7.66	ASPHERE(1)	0.744		
5	7.82	7.1693	3.314	1.492	57.8
6	7.61	ASPHERE(1)	2.657		
7	6.56	PLANO	0.330	1.550	55.0
8	6.49	PLANO	4.635		
9	4.94	PLANO	0.725	1.570	55.0
10	4.82	-28.9000			

\*DO NOT EXCEED LENS LENGTH 8.861

NOTES:

2) ASPHERIC SURFACE DESCRIBED BY SAG EQUATION:

$$X(Y) = \frac{CY^2}{1 + \sqrt{1 - (k+1)C^2Y^2}} + DY^4 + EY^6 + FY^8 + GY^{10} + HY^{12}$$

SURF. 1 C= 0.1627657 D= -0.9597174E-05 F= 0.8515111E-07  
k= -1.0784800 E= 0.6443622E-07 G= -0.8389589E-09  
VERTEX RADIUS (1/C) = 6.1438 H= 0.0000000E+00

SURF. 4 C= 0.2147075 D= 0.0000000E+00 F= 0.0000000E+00  
k= -0.9062283 E= 0.0000000E+00 G= 0.0000000E+00  
VERTEX RADIUS (1/C) = 4.6575 H= 0.0000000E+00

SURF. 6 C= -0.0832591 D= 0.6436675E-03 F= -0.3216570E-06  
k= 0.0000000 E= 0.7271238E-05 G= 0.2184924E-07  
VERTEX RADIUS (1/C) = -12.0107 H= 0.0000000E+00

TABLE 7

SURF.	CLEAR APER.	RADIUS	THICKNESS	INDEX	V-NUMBER
	6.00	DIAPHRAGM	17.000		
1	9.10*	ASPHERE(1)	3.339	1.492	57.8
2	8.74	-224.8469	0.210		
3	8.54	26.8436	1.423	1.583	30.1
4	7.61	ASPHERE(1)	0.939		
5	7.85	ASPHERE(1)	3.574	1.492	57.8
6	7.71	-16.4096	2.444		
7	6.64	PLANO	0.330	1.550	55.0
8	6.56	PLANO	4.635		
9	4.91	PLANO	0.725	1.570	55.0
10	4.81	-28.7621			

\*DO NOT EXCEED LENS LENGTH 9.485

NOTES:

3) ASPHERIC SURFACE DESCRIBED BY SAG EQUATION:



$$X(Y) = \frac{CY^2}{1 + \sqrt{1 - (k+1)C^2Y^2}} + DY^4 + EY^6 + FY^8 + GY^{10} + HY^{12}$$

SURF. 1	C= 0.1609088	D= 0.0000000E+00	F= 0.0000000E+00
	k= -1.3568420	E= 0.0000000E+00	G= 0.0000000E+00
	VERTEX RADIUS (1/C) = 6.2147	H= 0.0000000E+00	
SURF. 4	C= 0.2735529	D= 0.0000000E+00	F= 0.0000000E+00
	k= -1.5674930	E= 0.0000000E+00	G= 0.0000000E+00
	VERTEX RADIUS (1/C) = 3.6556	H= 0.0000000E+00	
SURF. 5	C= 0.2075765	D= -0.2473807E-02	F= 0.6771738E-06
	k= 0.0000000	E= -0.1801932E-04	G= -0.1057451E-06
	VERTEX RADIUS (1/C) = 4.8616	H= 0.0000000E+00	

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the scope of the invention.